The Number Race - computer-assisted intervention for mathematically low-performing first graders

Hellstrand, Heidi

2020-01-01

Hellstrand , H , Korhonen , J , Linnanmäki , K & Aunio , P 2020 , ' The Number Race - computer-assisted intervention for mathematically low-performing first graders ' , European Journal of Special Needs Education , vol. 35 , no. 1 , pp. 85-99 . https://doi.org/10.1080/13488678.2019.1615792

http://hdl.handle.net/10138/320453
https://doi.org/10.1080/13488678.2019.1615792

This is the final draft of the manuscript.

Accepted for publication in European Journal of Special Needs Education (12 April 2019). DOI: 10.1080/13488678.2019.1615792

The Number Race – computer-assisted intervention for mathematically low-performing first-graders

Heidi Hellstrand[a]*, Johan Korhonen[a], Karin Linnanmäki[a] and Pirjo Aunio[b]

[a]Faculty of Education and Welfare Studies, Åbo Akademi University, Vasa, Finland

[b] Faculty of Educational Sciences, University of Helsinki, Helsinki, Finland

* Corresponding author. E-mail address: heidi.hellstrand@abo.fi

Abstract

This manuscript presents a study in which the new version of the computer-based training programme, The Number Race (NR), was used as an intervention for mathematically low-performing children in grade one (M_{age} = 86.46, SD = 3.89). In addition to ordinary teacher instruction in mathematics, the intervention group (n = 29) received NR training for 15 minute sessions, 3–4 days per week, during a four-week period. One comparison group comprising mathematically low-performing children (n = 27) and another comprising average-performing children (n = 278) received only ordinary teacher instruction in mathematics during this period. The children's mathematical skills (e.g. counting and basic arithmetic skills) were measured three times during grade one, using three parallel tests. The grouping was based on the first assessment, using the lowest 20th percentile as the cut-off point in the test. The NR intervention took place between the second and third assessments. There was no statistically significant NR intervention effect found in this study.

Keywords

Computer-assisted interventions (CAI), low performance, mathematical learning, mathematical learning difficulties, mathematics game

Introduction

The learning of mathematical concepts and basic skills (e.g. counting, comparison, seriation, basic arithmetic) is practised as early as pre-school. Still, many children experience difficulty acquiring mathematical skills, with problems ranging from mild to severe (Geary 2011). In school, low-performing children seem to benefit less from ordinary instruction than their average-performing peers (Zhang et al. 2018). Computer technology has been suggested to complement average classroom instruction by providing intensive, individualised training for children in need of extra support (Praet and Desoete 2014; Räsänen et al. 2009). One way to utilise computer technology is through computer games, as they generally motivate children and can provide attractive possibilities for training in an entertainment context (Kroesbergen and Van Luit 2003; Wilson et al. 2006a). However, existing findings on the effectiveness of using computer technology in education have been contradictory (Chodura, Kuhn, and Holling 2015; Stultz 2017), ranging from the conclusion that it is less effective than teacher instruction (Dennis et al. 2016) to results suggesting its effectiveness (Chodura, Kuhn, and Holling 2015; Li and Ma 2010). The aim of this study was to examine the effect of a new version of the computer game, The Number Race (NR), as an intervention for mathematically low-performing children in grade one.

Mathematical performance in the early school years

There is a special interest in identifying children at risk for mathematical learning difficulties in order to provide them with early support (Geary 2011). The prevalence of mathematical learning disabilities (MLD), also called dyscalculia, is only about four to seven percent and refers to severe difficulties in acquiring basic mathematical skills. However, a larger proportion of children can be regarded as low-performing (i.e. low-achieving) in mathematics. Low-performing children can be identified as those who perform at or below the twenty-fifth percentile in validated mathematics tests (Geary 2011). Low-performing children in kindergarten and the early school years are often regarded as children at risk for mathematical learning difficulties.

Mathematical knowledge comprises a number of components, such as arithmetical knowledge, that are foundational for other mathematical areas: problem solving, algebra, measurement, and statistics (Dowker 2005). The best domain-specific predictors of arithmetical knowledge are symbolic number knowledge, including number identification and representation, cardinality and ordinality (De Smedt et al. 2013; Desoete et al. 2012; Merkley and Ansari 2016; Vanbist et al. 2018), applying counting principles (Stocke, Desoete, and Roeyers 2010), basic and advanced counting (Nguyen et al. 2016), and sophisticated counting strategies (Vanbist et al. 2018). The cardinality and ordinality principles are strongly related to the counting sequence skills (Gelman and Gallistel 1978). Counting and mastering the correct counting sequence is more than just correctly reciting number words by rote. In recent studies, the age at which cardinality is acquisitioned has strongly predicted later mathematical development (Geary et al. 2018). In the early years, non-symbolic number knowledge, including numerical magnitude estimations and comparisons, has been found important and a basis for operating with numerical symbolic representations and developing counting and arithmetical skills (Chen and Li 2014; Desoete et al. 2012; Griffin 2003; Hyde, Khanum, and Spelke 2014). However, symbolic number knowledge seems to be a stronger predictor in the long term than non-symbolic number knowledge (De Smedt et al. 2013; Desoete et al. 2012; Sasanguie et al. 2013; Schneider et al. 2017).

Computer-assisted intervention (CAI)

Computer-assisted intervention (CAI) uses a computer to present instructional material and monitor learning. The advantages of CAI include one-to-one interaction, high motivation, instantaneous response, possibility to proceed at one's own pace and level, individual attention, and multimodal presentation of concepts (Fengfeng, 2008). Previous studies have found that CAI can be used successfully in training mathematical skills (Baroody et al. 2013; Cheung and Slavin 2013; Chodura, Kuhn, and Holling 2015; Li and Ma 2010; Praet and Desoete 2014; Räsänen et al. 2009) and practising automatisation of mathematical skills (Sella et al. 2016). Adaptive computer games have an additional advantage, as they maintain the difficulty of an educational task, providing the child with exactly the required difficulty level (Wilson et al. 2006a).

Conversely, findings from meta-analyses (Seo and Bryant 2009; Stultz 2017) indicated that CAI did not show conclusive effectiveness in improving performance of children with MLD. Dennis and colleagues (2016) concluded the same in their meta-analysis of interventions for children with MLD, indicating that interventions using technology showed the weakest effect, compared to, for instance, peer-assisted learning and teacher-led instructions. Other studies confirm that computer games have not been shown to be more effective than teacher-led instruction (Kroesbergen and Van Luit 2003; Slavin and Lake

2008). While most educational computer games and internet applications for practicing numerical skills have focused on drill-and-practice rehearsal in a more colourful and motivating environment than textbooks, the tasks do not differ from those in textbooks (Räsänen 2015). Stultz (2017) states that even though previous studies have found support for the use of CAI to improve the performance of children with MLD, it is still unclear if CAI should be used to supplement or supplant classroom instructions. The contradictory findings and the lack of research about available CAI programmes and packages indicate that more controlled research is needed on the effects of CAI (Cheung and Slavin 2013; Räsänen et al. 2009). For example, Räsänen and colleagues (2009) point out that many CAI studies do not use control groups, and longitudinal studies are needed. Computers are suggested as a good complement to average classroom instruction, especially for low-performing children in mathematics (Baroody et al. 2013; Mononen et al. 2014).

CAI in mathematics for children in the early grades mainly focuses on basic numerical skills. To the best of our knowledge, the existing mathematics programmes and games that have been used in research-based CAIs for low-performing children in kindergarten and the early grades include Calcularis (Käser et al. 2013), GraphoGame Math (Salminen et al. 2015), Lola’s World (Aunio and Mononen 2018), and The Number Race (NR; Wilson et al. 2006b; Wilson et al. 2009; Räsänen et al. 2009; Salminen et al. 2015), which is used in this study. There have been a few studies on the effectiveness of the NR (version 2.0) in supporting mathematically low-performing children. The NR is specially designed to practice various number presentations and the transformations between symbolic and non-symbolic number representations, with a special focus on the representation of quantities and approximate numerical comparison (Wilson et al. 2006a). Previous studies have reported promising results from interventions with the NR game to improve mathematical skills in children with MLD (Wilson et al. 2006b; Wilson et al. 2009; Räsänen et al. 2009). However, in these studies, the participating children were kindergarteners (Räsänen et al. 2009; Salminen et al. 2015; Sella et al. 2016; Wilson et al. 2009) from a specific target group (low socio-economic status: Wilson et al. 2009; with MLD: Salminen et al. 2015; Wilson et al. 2006b), or the interventions were conducted in a highly controlled learning environment (Obersteiner, Reiss, and Ufer 2013). One previous study (Brankaer, Ghesquière, and De Smedt 2014) did not find any effects of the NR intervention, compared to a passive control group. The results from previously published NR studies have been critically discussed by Szűcs and Myers (2017), indicating that some previous studies have an inadequate design, either in that they lack a control group or that they contrast NR training with non-mathematical training (reading training or drawing activity). The previous studies used the initial version of the game (2.0) or their own modification of it (Obersteiner, Reiss, and Ufer 2013); none of the studies used the Swedish version of the game. This study contributes to the literature by using an updated Swedish version of the NR (*Tal i farten*, version 3.0) in an intervention involving low-performing first-graders. The updated version is in better agreement with recent studies on the format of the number line (Siegler and Ramani 2009) and focuses more on strengthening the connection between counting and basic addition than does the previous version of NR. The intervention study was conducted in an authentic school setting with low-performing children in the general classroom.

The present study

This study examined the effect of using the new version of the adaptive computer game, the NR, to enhance basic mathematical skills for grade one children who were deemed to be low-performing in mathematics. A quasi-experimental research design was used with a low-performing intervention group, a low-performing comparison group, and an average-performing comparison group. The following research questions were generated:

1. How does the NR intervention group develop in its overall mathematical performance, compared to the low- and average-performing comparison groups?
2. How does the intervention group develop in the different mathematical subskills (symbolic and non-symbolic number knowledge, understanding mathematical relations, and basic skills in arithmetic), compared to the low- and average-performing comparison groups?

Methods

Participants

A total 334 children (171 girls) were recruited from 23 schools in both urban and rural Swedish-speaking areas of Finland[1] for a longitudinal study with the aim of following the

[1] Bilingualism and the education system in Finland: Finland has two official languages, Finnish and Swedish. The Swedish-speaking population represents a minority (5.3%, according to Statistics Finland [2016]) and lives mainly in the coastal areas of Finland. Children start school in August of the year they turn seven and generally attend their neighborhood school. Compulsory formal education comprises nine years of comprehensive school.

children over their first year of formal education. In the initial stage of the longitudinal study, Swedish-speaking primary schools in Finland were contacted and informed about the aim and procedure of the study. A total of 23 schools were interested in participating in the longitudinal study, and permission was obtained from the principals and teachers. We asked the participating schools for further permission to conduct this intervention study. Written permission authorising the children's participation in all phases of the study was obtained from their parents, and parents were informed of their right to discontinue participation at any point.

The children's mathematical skills were assessed at three points during grade one. The first assessment (T1) took place at the beginning of the school year (August), the second assessment (T2) in January, and the third assessment (T3) at the end of the school year (May). The T1 assessment was used to identify low-performing children and to construct the intervention and low-performing comparison groups. The low-performing children were identified by using a cut-off point of the lowest 20th percentile on the mathematical test at T1 (Geary 2011). A total of 56 children were deemed low-performing in mathematics. Of these, 29 children from nine schools were selected for the intervention group based on geographical placement that made it possible for the research assistants to visit the schools. The remainder of the children formed the low-performing comparison (n = 27) and the average-performing group (n = 278).

Information on the children's home language was reported by the teachers. Most of the children spoke Swedish as a native language (81.4%). The next largest group of children were Finnish speaking (16.8%). Children self-reported their gender information by checking a box (boy or girl). All children attended neighbourhood schools and followed the general education system; no special education classes were included. The background characteristics of the participating children at the T1 assessment are presented in Table 1.

Mathematical measurement

A mathematical test was administered to assess the children's basic mathematical skills in grade one. The test (Koponen et al. 2011) is a screening battery based on a theoretical model of core numerical skills and was constructed by a multiprofessional and multilingual team within a national project. The test focuses on core numerical skills for learning mathematics: (1) symbolic and non-symbolic number knowledge, (2) understanding mathematical relations, (3) counting skills, and (4) basic skills in arithmetic.

The test is a paper-and-pencil assessment that can be carried out in groups while teachers give verbal instructions. To follow up children's development during the school year, three parallel tests are available in grade one. The first parallel test is more extensive than the two other parallel tests and covers tasks from all core skills. In the second and third parallel tests, no task focuses directly on counting skills, only the three other core skills are assessed. The content, the number of items, and the reliability values of the test are presented in Table 2. A more extensive analysis of the validity and the reliability of the test is presented in another manuscript (Authors 2014).

The Number Race

The NR computer game was originally developed by a French research group for remediation of dyscalculia in children ages 5–8 (Wilson et al. 2006a). The NR is adaptive and can vary in three ways: the distance between the numerical representations, the speed and response deadline, and the conceptual complexity (Wilson et al. 2006a). The difficulty is constantly adapted so that the child's performance stays at a 75% accuracy level. At the initial level, the game focuses on non-symbolic number skills, such as recognising numerical quantities and comparing numbers by choosing the larger of two quantities (Wilson et al. 2006a). At subsequent levels, symbolic number skills are more prominent, as the game improves the children's fluency in arithmetic and mapping numbers to quantities by adding or subtracting in order to make comparisons. The additions and subtractions are conceptually oriented, concrete operations instead of drills of arithmetical facts (Wilson et al. 2006a).

The new version of the NR (version 3) emphasises counting, basic arithmetic, and understanding of the number line. In the new version, basic arithmetic is denoted more visibly on the number line, and the number line is now continuous instead of divided into segments, as in the earlier version. Moving on the number line, the focus is on counting on instead of starting from the beginning. The total view is made clearer, and everything is on the same page: the number line, the two number boxes to choose from, and the comparison of magnitudes. The NR software is open source (GNU Public License) and can be freely downloaded from http://www.thenumberrace.com.

Procedure

The assessments were administered by classroom or special education teachers in a classroom setting during one or two lessons. The teachers received detailed, written information and were advised to strictly follow the written manuals for each assessment and to follow the order of the tasks in the test. Children worked individually at their own tables under the teacher's supervision. The tables were arranged so that children could not see each other's papers. If needed, the teachers could allow short breaks or divide the measurement session in two parts. The T1 assessment took approximately 60 minutes for the whole-group situation and an additional 10 minutes with each child individually for verbal counting tasks. The T2 and T3 assessments took approximately 40 minutes each and were conducted in whole-group situations. After each data collection session, the children's task papers were sent to the researchers for coding. Correct answers were awarded one point, and wrong or empty answers were awarded zero points. The children's names and schools were replaced with codes to secure anonymity.

The intervention was carried out in the schools for six weeks. The research assistants visited the schools to install the NR and to guide teachers towards accomplishing the intervention. During the intervention, the teachers were asked to keep a logbook of the process, for fidelity purposes. The information required in the logbook concerned the child's name, date of play, minutes of play, and some voluntary notes. Each participating child was encouraged to play the NR 3–4 times per week, for 15 minutes each time over a four-week period (April–May). The average play time on each occasion was 15.28 minutes (SD = 1.44), and the average number of sessions was 11.14 (SD = 1.36). The intervention was supervised by the teacher individually or in small groups, with children at their own computers using headsets.

The T2 assessment formed the pre-test prior to intervention, and the T3 assessment was used as a post-test after the intervention. All children in the NR group were present at the three assessments. For several reasons (e.g. illness, change of school), some children in the comparison groups were absent from assessments (T1: 13 children missing; T2: 19 children missing; T3: 28 children missing).

All participants followed the content of the first-grade national core curriculum for mathematics (Finnish National Board of Education [FNBE] 2004) and took part in ordinary classroom instruction in mathematics. These curriculum guidelines focus on learning, understanding, and performing operations with numbers, number symbols, and number words, mainly in the number range of 0–20. By the end of the first school year, numbers up to 100 are also introduced. The key areas are basic addition and subtraction, algebra, statistics, measurements, and geometry.

Analysis

Initially, we analysed the group differences between the three groups: the NR intervention group (n = 29), the low-performing comparison group (low-comparison, n = 27) and the average-performing comparison group (average-comparison, n = 278). The results of the analysis of variance (ANOVA) found no statistically significant group differences with respect to age, $F(2, 319) = 0.229$, $p = .80$. Regarding the home language (Swedish, Finnish, or other languages), no statistically significant differences were found among the three groups, $\chi^2(4, N = 334) = 3.176$, $p = .529$. In relation to gender, no statistically significant differences among the three groups were found, $\chi^2(2, N = 334) = 0.765$, $p = .682$.

In the main analysis, the performance within and between groups at T1, T2, and T3 were compared using separate ANOVAs. First, we analysed the overall mathematics performance at the three time points by conducting separate ANOVAs with post hoc comparison. The effectiveness of the NR intervention between T2 and T3, when the intervention took place, was analysed by conducting a 2 (T2 and T3) x 3 (NR group, low-comparison, and average-comparison) mixed factorial ANOVA. The partial eta squared (η^2_p) was used to measure the effect size. The test scores from the two time points were converted to standardised z-scores due to the different maximum scores in the T2 and T3 assessments. Levene's tests were used to answer whether the variance within groups was different. Furthermore, we looked specifically at the subskills and conducted multivariate analyses of variances (MANOVA) for each time point; we compared the NR group to the two comparison groups in symbolic and non-symbolic number knowledge, understanding mathematical relations, and basic skills in arithmetic. Counting skills were not measured at the T2 and T3 assessments. Finally, the notes from the logbooks were used as additional information on whether the playing time had an effect and how the children experienced playing the NR.

Results

Group differences in mathematical performance over time

The ANOVAs revealed large significant differences between the groups in overall mathematical performance at T1, T2, and T3 (Table 3). The post hoc comparisons indicated that there were significant differences between the NR group and the average-performing group ($p < .001$) and between the low-comparison group and the average-comparison group

($p < .001$) at all timepoints. The difference between the NR group and the low-comparison group in overall mathematical performance was not significant at any of the timepoints.

To investigate group differences in the overall development of math performance from T2 to T3, a 2x3 factorial ANOVA was conducted. The time * group interaction was not significant, indicating there were no group differences in the development of mathematical performance, $F(2, 297) = 0.60$, $p = .549$, $\eta^2_p = .004$.

Group differences in mathematical subskills

Next, we investigated group differences in the performance of mathematical subskills (symbolic and non-symbolic number knowledge, NK; mathematical relations, MR; counting skills, CS; and basic skills in arithmetic, BA) at all three time points. The MANOVA test revealed a large statistically significant main effect for the group on the subskills at T1 (Table 3). The results were similar when looking at the subskills separately. Levene's test found that the assumption of homogeneity of variance was not met: NK ($p = .011$), MR ($p < .001$), CS ($p = .027$), and BA ($p < .001$). The post hoc comparison indicated that there were significant differences between the NR group and the average-comparison group for all subskills, as well as between the low-comparison group and the average-comparison group. The difference between the NR group and the low-performing comparison group at T1 was not statistically significant in any of the subskills.

Comparing the performance of the NR and comparison groups in relation to subskills at T2, the MANOVA test revealed a large statistically significant main effect for the groups (Table 3). The results were similar when looking at the subskills separately. Levene's test found that the assumption of homogeneity of variance was not met: NK ($p < .001$), MR ($p < .001$), and BA ($p < .001$). The post hoc comparison indicated there were significant differences between the NR group and the average-comparison group for all subskills, as well as between the low-comparison and average-comparison groups. The difference between the NR and low-comparison groups in the subskills at T2 was not statistically significant.

Comparing the performance of the NR and comparison groups in relation to subskills at T3, the MANOVA test revealed a large statistically significant main effect for the groups (Table 3). The results were similar when looking at the subskills separately. Levene's test found that the assumption of homogeneity of variance was not met concerning NK ($p < .001$) or BA ($p < .001$) but was met for MR ($p = .135$). The post hoc comparison indicated that there were significant differences between the NR group and the average-comparison group at the subskills, as well as between the low-comparison and average-comparison groups. The difference between the NR group and the low-comparison group in the subskills at T3 was not statistically significant.

Intervention duration, intensity, and experiences

The information from the logbooks revealed no statistically significant correlation between the minutes of play and performance at the T3 assessment ($r(27) = .057$, $p = .768$) or between the occasions of play and performance at the T3 assessment ($r(27) = -.193$, $p = .317$). Five teachers (28%) commented on their students' ($n = 16$) play experiences. The teachers' comments revealed that most of the children in the NR groups had positive play experiences, especially at the beginning of the intervention. For some participating children, motivation decreased at the end of the intervention, as the game felt boring and repetitious or took too long to reward the children.

Discussion

This study used a quasi-experimental research design to investigate the effectiveness of the NR computer game in enhancing low-performing first grade children's mathematical performance. The target group received CAI using the NR as a supplement to ordinary classroom instruction over a four-week period. Two comparison groups were constructed, one with low-performing children and the other with average-performing children. The children's mathematical performance was assessed at three time points during the school year, and the intervention took place between the second and third assessments.

Our main finding was that there was no statistically significant intervention effect on children's mathematical performance. At none of the time point assessments did the low-performing groups differ significantly, indicating that the effect of the NR intervention did not exceed the improvements of the low-comparison group, which only received ordinary classroom instruction in mathematics during the four-week intervention period. The average-performing children outperformed the low-performing children at all time points.

The advantages of CAI in general have been the one-to-one interaction, high motivation, instantaneous response, the possibility to proceed at one's own pace and level, individual attention, and multimodal presentation of concepts (Fengfeng, 2008). Even though the NR provides these benefits, the performance of children in our NR intervention group did not improve more than that of their peers in the low-comparison group. In previous studies on the effectiveness of the NR in supporting low-performing children in mathematics, results have been promising (Obersteiner et al. 2013; Räsänen et al. 2009; Sella et al. 2016; Wilson et al. 2006b; Wilson et al. 2009). As our results contradict these studies, it is worth highlighting the differences between our and previous studies. We suggest that the differences between our results and previous studies' results originate from the characteristics of our target group, the skills that were practised in the NR, and the location of the study. Our target children were low-performing first-graders (below the 20th percentile), hence a homogenous group of children, compared to the preschool children with (or at risk of) dyscalculia in previous studies (Salminen et al. 2015; Wilson et al. 2006b; Wilson et al. 2009). The NR is aimed at enhancing non-symbolic and symbolic number knowledge, practising the links between number representations, conceptualising and automating arithmetic, and emphasising approximate non-symbolic and symbolic comparison (Wilson et al. 2006a). It is possible that the children in the intervention group had already mastered these skills on a higher level than the NR could provide practice.

Overall, children benefit from extra support, but individualised interventions focusing on specific components seem to be more effective than interventions that disregard individual differences (Dowker and Sigley 2010). It could be that children in our study would have benefitted from training other skills, such as exact numerosities and number symbols, as there is a developmental shift from focus on non-symbolic number knowledge to symbolic number knowledge in early school years (Desoete et al. 2012). It might also be that, during the intervention sessions, the children in the comparison groups received mathematics instruction in the ordinary classroom setting, which met the educational needs of low-performing first-graders better than the NR game.

As the duration and intensity of the intervention in our study were similar to that of previous NR studies (Obersteiner, Reiss, and Ufer 2013; Räsänen et al. 2009; Wilson et al. 2006b; Salminen et al. 2015), they are not likely to be the major reason for result dissimilarity. In previous studies, only Räsänen and colleagues (2009) and Salminen and colleagues (2015) conducted their studies in authentic (pre)school settings as we did. When intervention studies are conducted in children’s daily environments, it is challenging to control for distracting factors and get good intervention effects (Aunio and Mononen 2018).

There are some limitations in our study related to measurements. With regard to the specific skills trained in the NR, the mathematical test we used was probably not sensitive enough. The results might have differed if the skills tested more closely matched the skills trained in the NR, such as using computerised tests to measure the performance and fluency of symbolic and non-symbolic number processing (Sasanguie et al. 2013; Schneider et al. 2017). The mathematical test focused on basic arithmetic tasks, whereas the NR focused on symbolic and non-symbolic number knowledge, especially quickly recognising and comparing magnitudes and numbers. A computerised test would also have been similar to the way children were practicing their skills. Additionally, it would have been valuable to measure long-term effects of the intervention in terms of delayed measurement. So far, only Räsänen and colleagues (2009) have reported results from a delayed post-test related to the NR intervention. Therefore, long-term training effects of the NR and CAI need to be investigated in the future.

As classrooms evolve towards e-classrooms and textbooks are replaced or complemented with e-books, we need more research on the effectiveness of CAI (Cheung and Slavin, 2013; Räsänen 2015). Our results have particular implications for planning effective interventions for low-performing children in mathematics that can be implemented by teachers in the everyday school setting. It is primarily important to discuss interventions with positive outcomes and situations in which interventions worked (Dowker and Sigley 2010). Therefore, it is also important to learn from studies in which CAI does not appear to be as effective as predicted. When there are several commercial products available, it is particularly important to report different kind of studies, and to use targeted interventions (Räsänen et al. 2009).

The present study demonstrated no statistically significant short-term improvement in the mathematical performance of low-performing children who played the NR for a four-week period, relative to the performance of comparison groups. However, previous NR studies have shown improvement in children’s basic numerical skills, especially among kindergarteners, children from low-socioeconomic families, and children with MLD (Obersteiner et al. 2013; Räsänen et al. 2009; Sella et al. 2016; Wilson et al. 2006b; Wilson et al. 2009). The efficacy of CAI as a supplement to average classroom instruction has been underpinned in many other studies (e.g. Praet and Desoete 2014). CAI can provide training in an entertaining and motivational context, immediate and continuous responses, and the ability to work independently (Praet and Desoete 2014). It is thus valuable to continue research on educational interventions to support children with various needs in their mathematics learning.

References

Aunio, P., and R. Mononen. 2018. ‘The Effects of Educational Computer Game on Low-Performing Children’s Early Numeracy Skills: An Intervention Study in a Preschool Setting.’ *European Journal of Special Needs Education* 33 (5): 677–691. doi:10.1080/08856257.2017.1412640.

Baroody, A.J., M.D. Eiland, D.J. Purpura, and E.E. Reid. 2013. ‘Can Computer-Assisted Discovery Learning Foster First Graders’ Fluency With the Most Basic Addition Combinations?’ *American Educational Research Journal* 50 (3): 533–573. doi:10.3102/0002831212473349.

Brankaer, C., Ghesquière, P., and De Smedt, B. 2014. ‘Onderzoek naar het effect van De Getallenrace: een computerprogramma om getalgevoel te stimuleren bij kinderen met rekenproblemen [An Investigation of the Effectiveness of the Number Race Game: A Computerized Intervention to Stimulate Number Sense in children With Mathematical Difficulties]’. In Zorg dragen voor kinderen en jongeren met leerproblemen. Handvatten voor goede praktijk, edited by P. Ghesquière, A. Desoete, and C. Andries, 59–71. Leuven: Acco.

Chen, Q., and J. Li. 2014. ‘Association Between Individual Differences in Non-Symbolic Number Acuity and Math Performance: A Meta-analysis.’ *Acta Psychologica* 148: 163–172. doi:10.1016/j.actpsy.2014.01.016.

Cheung, A. C. K., and R.E. Slavin. 2013. ‘The Effectiveness of Educational Technology Applications for Enhancing Mathematics Achievement in K-12 Classrooms: A Meta-analysis.’ *Educational Research Review* 9: 88–113. doi:10.1016/j.edurev.2013.01.001.

Chodura, S., J-T. Kuhn, and H. Holling. 2015. ‘Interventions for Children with Mathematical Difficulties. A Meta-analysis.’ *Zeitschrift für Psychologie* 223 (2): 129–144. doi:10.1027/2151-2604/a000211.

Dehaene, S., O. Maslov, P. Räsänen, et al. 2012. The Number Race, version 3.0. http://sourceforge.net/projects/numberrace.

Dennis M. S., E. Sharp, J. Chovanes, A. Thomas, R.M. Burns, B. Custer, and J. Park. 2016. ‘A Meta-analysis of Empirical Research on Teaching Students with Mathematics Learning Difficulties.’ *Learning Disabilities Research & Practice,* 31 (3): 1-13. doi:10.1111/ldrp.12107.

De Smedt, B., M-P. Noël, C. Gilmore, and D. Ansari. 2013. ‘How Do Symbolic and Non-Symbolic Numerical Magnitude Processing Skills Relate to Individual Differences in Children's Mathematical Skills? A Review of Evidence from Brain and Behavior.’ *Trends in Neuroscience and Education* 2 (2): 48–55. doi:10.1016/j.tine.2013.06.001.

Desoete, A., A. Ceulemans, F. De Weerdt, and S. Pieters. 2012. ‘Can We Predict Mathematical Learning Disabilities from Symbolic and Non-Symbolic Comparison Tasks in Kindergarten? Findings from a Longitudinal Study.’ *British Journal of Educational Psychology* 82: 64–81. doi:10.1348/2044-8279.002002.

Dowker, A. 2005. *Individual Differences in Arithmetic: Implications for Psychology, Neuroscience and Education.* Hove: Psychology Press.

Dowker, A. and G. Sigley. 2010. Targeted Interventions for Children with Arithmetical Difficulties. *British Journal of Educational Psychology* 7: 65–83. doi:10.1348/97818543370009X12583699332492.

Fengfeng, K. 2008. ‘A Case Study of Computer Gaming for Math: Engaged Learning from Gameplay?’ *Computers and Education* 51 (4): 1609–1620. doi:10.1016/j.compedu.2008.03.003.

Finnish National Board of Education (FNBE). 2004. National Core Curriculum for Basic Education 2004. http://www.oph.fi/english/currcula_and_qualification/basic_education.

Geary, D. 2011. ‘Consequences, Characteristics, and Causes of Mathematical Learning Disabilities and Persistent Low Achievement in Mathematics.’ *Journal of Developmental and Behavioral Pediatrics* 32 (3): 250–63. doi:10.1097/DBP.0b013e318209edef.

Geary, D. C., K. vanMarle, F.W. Chu, J. Rouder, M.K. Hoard, and L. Nugent. 2018. ‘Early Conceptual Understanding of Cardinality Predicts Superior School-entry Number-system Knowledge.’ *Psychological Science* 29 (2): 191–205. doi:10.1177/0956797617729817.

Gelman, R., and C. Gallistel. 1978. *The Child's Understanding of Number.* Cambridge, MA. Harvard University Press.

Griffin, S. 2003. ‘The Development of Math Competence in the Preschool and Early School Years.’ In *Mathematical Cognition* edited by J.M. Royer, 1–32. Greenwich, CN: Information Age publishing.

Hyde, D.C., S. Khanum, and E.S. Spelke. 2014. ‘Brief Non-Symbolic, Approximate Number Practice Enhances Subsequent Exact Symbolic Arithmetic in Children.’ *Cognition* 131 (1): 92–107. doi:10.1016/j.cognition.2013.12.007.

Koponen, T., J. Salminen, P. Aunio, J. Polet, and H. Hellstrand. 2011. ‘LukiMat – Bedömning av lärandet: Identifiering av stödbehov i matematik i årskurs 1. Handbok.’ [LukiMat – Assessment for Learning: Identifying Children in Need of Support in Mathematics in

First Grade]. http://www.lukimat.fi/lukimat-bedomning-av-larandet/material/identifiering-av-stodbehov/ak-1/1-mat-handbok.

Kroesbergen, E. and J. Van Luit. 2003. ‘Mathematics Interventions for Children with Special Educational Needs: A Meta-analysis.’ *Remedial and Special Education* 24 (2): 97–114. doi:10.1177/07419325030240020501.

Käser, T., G. Baschera, J. Kohn, J., K. Kucian, V. Richtmann, U. Grond, M. Gross, and M. von Aster. 2013. ‘Design and Evaluation of the Computer-Based Training Program Calcularis for Enhancing Numerical Cognition.’ *Frontiers in Psychology,* 4: 1–13. doi:10.3389/fpsyg.2013.00489.

Li, Q., and X. Ma. 2010. ‘A Meta-Analysis of the Effects of Computer Technology on School Students’ Mathematics Learning.’ *Educational Psychology Review* 22 (3): 215–243. doi:10.1007/s10648-010-9125-8.

Merkley, R., and D. Ansari. 2016. ‘Why Numerical Symbols Count in the Development of Mathematical Skills: Evidence from Brain and Behavior.’ *Current Opinion in Behavioral Sciences* 10: 14-20. doi:10.1016/j.cobeha.2016.04.006.

Mononen, R., P. Aunio, T. Koponen, and M. Aro. 2014. ‘A Review of Early Numeracy Interventions for Children at Risk in Mathematics.’ *International Journal of Early Childhood Special Education* 6 (1): 25–54. doi:10.20489/intjecse.14355.

Nguyen, T., T. Watts, G. Duncan, D. Clements, J. Sarama, C. Wolfe, and M. Spitler. 2016. ‘Which Preschool Mathematics Competencies Are Most Predictive of Fifth Grade Achievement?’ *Early Childhood Research* 36 (3): 550–560. doi:10.1016/j.ecresq.2016.02.003.

Obersteiner, A., K. Reiss, and S. Ufer. 2013. ‘How Training on Exact or Approximate Mental Representations of Number Can Enhance First-Grade Students’ Basic Number

Processing and Arithmetic Skills.' *Learning and Instruction* 23: 125–135. doi:10.1016/j.learninstruc.2012.08.004.

Praet, M., and A. Desoete. 2014. 'Enhancing young children's arithmetic skills through non-intensive, computerised kindergarten interventions: A randomised controlled study.' *Teaching and Teacher Education* 39: 56–65. doi:10.1016/j.tate.2013.12.003.

Räsänen, P. 2015. 'Computer-Assisted Interventions on Basic Number Skills.' In *The Oxford Handbook of Numerical Cognition*, edited by R. Cohen Kadosh and A. Dowker, 745–766. Oxford: Oxford University Press.

Räsänen, P., J. Salminen, A. Wilson, P. Aunio, and S. Dehaene. 2009. 'Computer-Assisted Intervention for Children with Low Numeracy Skills.' *Cognitive Development* 24 (4): 450–472. doi:10.1016/j.cogdev.2009.09.003.

Salminen, J., T. Koponen, M. Leskinen, A. Poikkeus, and M. Aro. 2015. 'Individual Variance in Responsiveness to Early Computerized Mathematics Intervention.' *Learning and Individual Differences* 43: 124–131. doi:10.1016/j.lindif.2015.09.002.

Sasanguie, D., S.M. Göbel, K. Moll, K. Smets, and B. Reynvoet. 2013. 'Approximate Number Sense, Symbolic Number Processing, or Number–Space Mappings: What Underlies Mathematics Achievement?' *Journal of Experimental Child Psychology* 114 (3), 418–431. doi:10.1016/j.jecp.2012.10.012.

Schneider, M., K. Beeres, L. Coban, S. Merz, S.S. Schmidt, J. Stricker, B. De Smedt. 2017. 'Associations of Non-symbolic and Symbolic Numerical Magnitude Processing with Mathematical Competence: A Meta-analysis.' *Developmental Science* 20: e12372. doi:10.1111/desc.12372.

Seo, Y., and D. Bryant. 2009. 'Analysis of Studies of the Effects of Computer-Assisted Instruction on the Mathematics Performance of Students with Learning Disabilities.' *Computers and Education*, 53: 913–928. doi:10.1016/j.compedu.2009.05.002.

Sella, F., P. Tressoldi, D. Lucangeli, and M. Zorzi. 2016. ‘Training Numerical Skills with the Adaptive Videogame “The Number Race”: A Randomized Controlled Trial on Preschoolers.’ *Trends in Neuroscience and Education,* 5: 20–29. doi: 10.1016/j.tine.2016.02.002.

Siegler, R., and G. Ramani. 2009. ‘Playing Linear Number Board Games—But Not Circular Ones—Improves Low-Income Preschoolers’ Numerical Understanding.’ *Journal of Educational Psychology* 101 (3): 545–560. doi:10.1111/j.1467-7687.2008.00714.x.

Slavin, R., and C. Lake. 2008. ‘Effective Programs in Elementary Mathematics: A Best Evidence Synthesis.’ *Review of Educational Research* 78 (3): 427–455. doi:10.3102/0034654308317473.

Statistics Finland. 2015. Population Structure. Retrieved from http://www.tilastokeskus.fi/til/vaerak/tau_en.html.

Stultz, S.L. 2017. ‘Computer-Assisted Mathematics Instruction for Students with Specific Learning Disability: A Review of the Literature.’ *Journal of Special Education Technology* 32 (4): 210–219. doi:10.1177/0162643417725881.

Szűcs, D. and T. Myers. 2017. ‘A Critical Analysis of Design, Facts, Bias and Inference in the Approximate Number System Training Literature: A Systematic Review.’ *Trends in Neuroscience and Education* 6: 187–203. doi:10.1016/j.tine.2016.11.002.

Vanbist, K., E.Ceulemans, L. Peters, P. Ghesquière, and B. De Smedt. 2018. ‘Developmental trajectories of children’s symbolicnumerical magnitude processing skills andassociated cognitive competencies.’ *Journal of Experimental Child Psychology* 166: 232–250. doi: 10.1016/j.jecp.2017.08.008.

Wilson, A., S. Dehaene, O. Dubois, and M. Fayol. 2009. ‘Effects of an Adaptive Game Intervention on Accessing Number Sense in Low-Socioeconomic-Status Kindergarten

Children.' *Mind, Brain, and Education* 3 (4): 224–234. doi:10.1111/j.1751-228X.2009.01075.x.

Wilson, A., S. Dehaene, P. Pinel, S. Revkin, L. Cohen, and D. Cohen. 2006a. 'Principles Underlying the Design of "The Number Race", an Adaptive Computer Game for Remediation of Dyscalculia.' *Behavioral and Brain Functioning* 2 (1): 19. doi:10.1186/1744-9081-2-19.

Wilson, A., S. Revkin, D. Cohen, L. Cohen, and S. Dehaene. 2006b. 'An Open Trial Assessment of "The Number Race", an Adaptive Computer Game for Remediation of Dyscalculia.' *Behavioral and Brain Functioning* 2 (1): 20. doi:10.1186/1744-9081-2-20.

Zhang, X., P. Räsänen, T. Koponen, K. Aunola, M. Lerkkanen, and J. Nurmi. 2018. 'Early Cognitive Precursors of Children's Mathematics Learning Disability and Persistent Low Achievement: A 5-Year Longitudinal Study.' *Child Development*. doi:10.1111/cdev.13123.

TABLES

Table 1. Descriptive statistics of the participants at T1.

	Gender		Age		Language		
	girls	boys	*M (SD)*	[min, max]	Swedish	Finnish	Other
NR-group	17	12	86.24 (4.79)	[80, 97]	22	6	1
Low-comparison group	13	14	86.04 (3.91)	[80, 96]	25	2	0
Average-comparison group	141	137	86.53 (3.79)	[79, 110]	225	48	5
All	171	163	86.46 (3.89)	[79, 110]	272	56	6

Note: Data from T1.

Table 2. Number of items, the reliability coefficients and the content in the mathematical test in first grade (three parallel tests).

	Test 1		Test 2		Test 3	
	items	α	Items	α	items	α
Symbolic and non-symbolic number knowledge (NK)	12	.79	6	.82	6	.80
Understanding mathematical relations (MR)	16	.71	6	.81	6	.86
Counting skills (CS)	17	.85	-	-	-	-
Basic skills in arithmetic (BA)	16	.78	24	.90	20	.94
Total	61	.91	36	.88	32	.95

Note. α = Cronbach's alpha.

Table 3. Mathematics performance at the three time points for the NR-group, the low-comparison group, and the average-comparison group.

		All		NR-group		Low-comparison		Average-comparison		Wilk's Λ	*F*(*df1*, *df2*)	*p*	η^2_p
		N = 334		*N* = 29		*N* = 27		*N* = 278					
		M (SD)	[max, min]	M (SD)	[max, min]	M (SD)	[max, min]	M (SD)	[max, min]				
T1													
Total	(max 61)	48.74 (9.02)	[17, 61]	34.17 (4.57)^{b}	[22, 39]	32.63 (5.56)^{b}	[17, 39]	51.97 (5.74)	[39, 61]		*F*(2, 318) = 251.239	< .001	.612
										.368	*F*(2, 317) = 50.837	< .001	.393
NK	(max 12)	8.79 (2.83)	[1, 12]	4.90 (1.70)^{a}	[1, 9]	6.00 (2.35)^{b}	[2, 11]	9.46 (2.45) ^{c***}	[3, 12]		*F*(2, 317) = 72.975	< .001	.315
MR	(max 16)	13.26 (2.34)	[1, 16]	10.66 (2.82)^{a}	[1, 15]	10.37 (2.87)^{b}	[4, 14]	13.82 (1.78) ^{c***}	[8, 16]		*F*(2, 317) = 62.244	< .001	.282
CS	(max 17)	13.26 (3.65)	[1, 17]	8.34 (2.45)^{a}	[4, 13]	7.30 (3.51)^{b}	[1, 13]	14.41 (2.59) ^{c*}	[5, 17]		*F*(2, 317) = 136.183	< .001	.462
BA	(max 16)	13.42 (2.63)	[5, 16]	10.28 (3.22)^{a}	[5, 16]	9.23 (2.10)^{b}	[5, 13]	14.17 (1.85) ^{c***}	[9, 16]		*F*(2, 317) = 108.564	< .001	.407
T2													
Total	(max 36)	29.06 (5.76)	[6, 36]	22.14 (6.69)^{b}	[6, 33]	23.41 (4.99)^{b}	[14, 32]	30.29 (4.83)	[8, 36]		*F*(2, 312) = 49.104	< .001	.239
										.731	*F*(2, 299) = 16.784	< .001	.145
NK	(max 6)	5.35 (1.23)	[1, 6]	4.42 (1.90)^{b}	[1, 6]	4.36 (1.81)^{b}	[1, 6]	5.54 (0.98)	[1, 6]		*F*(2, 299) = 17.575	< .001	.105
MR	(max 6)	4.35 (1.71)	[1, 6]	3.07 (1.27)^{b}	[1, 6]	2.77 (1.11)^{b}	[1, 6]	4.62 (1.67)	[1, 6]		*F*(2, 299) = 23.908	< .001	.138
CS	-	-	-	-	-	-	-	-	-		-	-	-
BA	(max 24)	19.61 (3.81)	[2, 24]	15.21 (5.14)^{b}	[2, 23]	16.27 (3.94)^{b}	[8, 23]	20.37 (3.13)	[8, 24]		*F*(2, 299) = 38.083	< .001	.203
T3													
Total	(max 32)	31.90 (5.71)	[3, 38]	24.38 (5.41)^{b}	[14, 35]	25.86 (6.77)^{b}	[13, 35]	33.25 (4.58)	[3, 38]		*F*(2, 303) = 61.351	< .001	.289
										.698	*F*(2, 297) = 19.362	< .001	.165
NK	(max 6)	5.08 (1.10)	[1, 6]	3.96 (1.48)^{b}	[1, 6]	4.10 (1.45)^{b}	[1, 6]	5.28 (0.90)	[2, 6]		*F*(2, 297) = 30.951	< .001	.172
MR	(max 6)	4.37 (1.90)	[1, 6]	2.86 (1.76)^{a}	[1, 6]	2.43 (1.54)^{a}	[1, 6]	4.69 (1.76)	[1, 6]		*F*(2, 297) = 26.049	< .001	.149
CS	-	-	-	-	-	-	-	-	-		-	-	-
BA	(max 20)	17.57 (2.99)	[2, 20]	14.41 (3.79)^{b}	[7, 20]	15.38 (3.69)^{b}	[7, 20]	18.10 (2.50)	[2, 20]		*F*(2, 297) = 33.867	< .001	.186

Note: NK = symbolic and non-symbolic number knowledge; MR = understanding mathematical relations; CS = counting skills; BA = basic skills in arithmetic. Group means within a row sharing the same superscripts are not significantly different at the *p* <.05 level with [a]Bonferroni correction/ [b]Tamhanes post hoc test due to unequal variances.